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Digital Color Classification for Colorful Cross Stitch Threads Using RGB+Euclidean Distance and LAB+CIE94

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Abstract — This paper presents an approach of converting a digital image to a cross stitch pattern. The color space of the input image is quantized and classified into the nearest thread colors using k-NN classifier. Two different metrics are tested, i.e. CIE94 (which using LAB color space) and Euclidean Distance (which using RGB color space). The outputs are validated both quantitatively (using Color Coherent Vector/ CCV) and qualitatively (through human perception). The results have shown that CIE94 works best for grayscale and monochrome patterns, while Euclidean distance is more suitable for color patterns.

Keywords— color classification, color space quantization, cross stitch pattern, dmc thread

I. INTRODUCTION

Digital technology development affects all human life, even when it comes to the realm of embroidery stitch art. The digital images can be processed into a cross stitch pattern which can guide embroider.

Just like the digital images, every cross stitch pattern has color values and coordinates of each point. The difference between the digital image result and the embroidery stitch pattern is the number of colors. The total color of 24-bit color image is $2^{24} = 16.777.216.000 = 16, 7$ million colors. While embroidery stitch color is only about 200-500 colors depending on what brand that produce the thread.

The oldest colorful cross stitch discovered in America in 1953, it is named Cross Stitch Sampler. It is colorful, shaded, such as painting. Created by Loara Standish, the daughter of Captain Myles Standish in Pilgrim Hall-Plymouth-Massachusetts. At that time thread color is not as much as now. Thread color limitation limit the creation of work [2], but now there are hundreds of threads colors also available.

TABLE I DMC THREAD DATA (3 SAMPLES)

RGB			LAB			DMC	DMC	Color
R	G	B	L	A	B	codeclass	classname	Preview
255	251	139	96.8687	-13.6373	53.8277	445	Lemon-LT	
114	132	60	52.2934	-18.2545	36.2389	469	Avocado Green	
59	118	143	46.8033	-11.5128	-19.4323	517	Wedgewood-MD	

The researcher making research of converting a digital image into a cross stitch pattern, using 360 colors of DMC brand threads. Each DMC brand thread has a code class a

codename, and RGB values as shown in Table 1. The researcher added the value of LAB color that is obtained from RGB value, which using RGB to LAB conversion formula.

The hypothesis is to find the each pixel's closest thread color to digital color that is shown in the digital image, and this method will conduct a good cross stitch pattern. The issue is the method of how to do the color measurement, because by using a different measure instrument, the color result will be different. A different color result will have an impact on the codebook and then finally the cross stitch pattern will be different as well.

II. RELATED WORK

The research about color space quantization done by Wang [3], that mention the purpose of the color space quantization is to:

- (1) To reduce color histogram dimension in order to minimize the storage requirement and to increase the speed of similarity measure;
- (2) To formulate a relatively small set of representative color bins from the entire color space as a reference color set for histogram calculation. Since perceptually similar colors are expected to be in the same quantized color bin to better match human perception of similarity, the quantization procedure should be performed in a perceptually uniform color space.

In Wang's color space quantization, it is advised to do use a perceptually uniform color space. An RGB color space is not linear and advised to use CIE LAB color space. However, Wang mentioned that: "there is no consistency in agreement on the choice of a color space".

The color space quantization started with changing 256 level (8 bit) color to 16 level (4 bit) and later got 4096 digital colors to be converted into HVC color, the final result is color bin as needed. This will create codebook RGB+Euclidean Distance.

The previous works about color classification [4] is to classify a skin color within a digital image, separate skin and not skin image. The color classification done in this research is a different kind, in this research, color classification is about classifying quantized digital colors into the available cross stitch thread colors.

The color space quantization done by Manjunath [11], which creating HMMD color space is to construct maximum 184 level quantized color for MPEG-7. For more requirement of quantized color, a different quantization method needed.

The classification [4] using k-Nearest Neighbor. k-NN method perhaps is the most straightforward classifier in the arsenal or machine learning techniques is the Nearest Neighbor Classifier – classification [5]

When is the k-NN is an effective and efficient way to make classification and regression? Beyer [1] making research from datasets which has minimum 50 thousand data each and dimensionality varied between 1 and 100. In 1 dimension, Nearest Neighbor is giving the maximum contrast of the nearest object and farthest object. The higher dimensionality of a dataset, the contrast is more and more reduced. At 20 dimensions the Nearest Neighbor will not be accurate by showing a bad result.

III. THE PROPOSED METHOD

The process of making cross stitch pattern with the k-Nearest Neighbor method by using two different metrics will conduct a different cross stitch pattern result. Which method is better will be validated and reviewed:

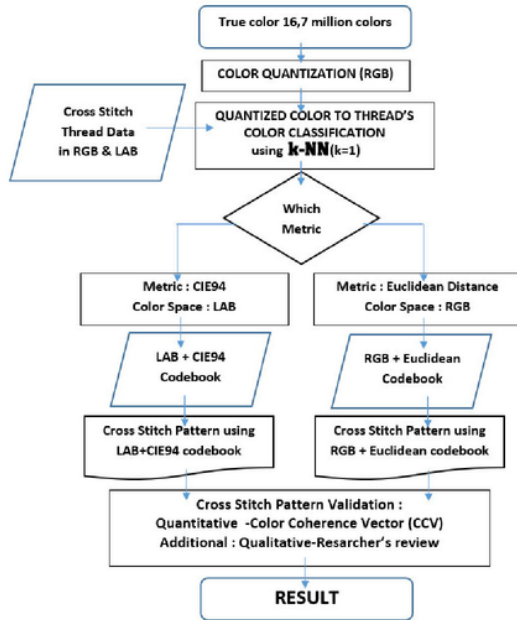


Fig 1. The flowchart of the proposed method

A. Color Space Quantization

The first process is started with making an RGB color space quantization, the reason is the thread color is using RGB, this quantization purpose is to reduce the 16.7 million of colors. This color space quantization is necessary in order to make the next process (color classification) faster.

The color space quantization method is different from

Wang. The researcher takes the RGB color space and divides it using an interval of 10 for each 3D r, g, and b line. Any unit number 1 up to 4 will be floored down to 0, and 5 up to 9 will be ceilinged up to 10. Example: 43 becomes 40, 139 becomes 140. Yet the exception is when the number is 255, it will stays 255, because each RGB line maximum is 255.

The quantization method is done equally to the Red (R). Green (G), Blue (B) line, and the formula is:

$$f(x) = \begin{cases} 255 & \text{if } x \geq 255 \\ \text{floor} \left(\frac{x+5}{10} \right) & \text{ot } \text{erwise} \end{cases} \quad (1)$$

This Red (R) line starts from 0 to 255 = 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160, 170, 180, 190, 200, 210, 220, 230, 240, 250, and 255.

This same quantization is done for the Green and Blue line. So each of the line has 27 data, then the RGB color space has digital color variables of = 27 (red) x 27 (green) x 27 (blue) = 19683 color variables.

From this quantization, there will be no more R11 G235 B28 because it is already rounded into R10 G240 B30 by the color space quantization.

Compared to Wang's color space quantization, the final variable result is 19683 color variables. Compared Wang's is 4096 color variables. This doesn't say one is better than the other but color quantization should be done depends on the need.

This color space quantization of interval 10 is making 19683 variable colors for the RGB color space.

DMC cross stitch threads are not equally spread in the RGB color space as shown in Figure 1, the distance between them are different. Some thread color has a little difference for the distance to its nearest thread color. So there will be no color thread is removed in the codebook.

Solve the problem of RGB color space that is said has non-uniform color space and unsuitable for color distance measurement. By making quantization interval of 10, more detail, it is hypothesized to cover the RGB's weakness

B. Color Classification

All 19683 quantized colors value will be classified into one of the thread color value. To make the classification, the k-Nearest Neighbor algorithm is chosen, because it's simple yet rapid process also the dimension of the data is only 3 (for RGB or LAB)

In the k-NN process, k=1 is used, this means the nearest object will be representing the quantized color value through classification. The collection of all classified colors is called codebook. The k=1 is also for a normal NN problem [1]

The nearest distance result in this process is not absolute, it depends on which metric is used. Different metric will conduct a different result. In this research, there will be 2 metric used:

RGB + Euclidean Distance: Euclidean Distance will measure the distance between quantized RGB color values to a thread's RGB color value.

The formula of Euclidean Distance [6] :

$$d(q, p) = \sqrt{(q_1 - p_1)^2 + (q_2 - p_2)^2 + \dots + (q_n - p_n)^2} \quad (2)$$

E.g.: For R90 G100 B30, searching the nearest value color thread using k-NN (k=1) and the metric used is Euclidean Distance. The thread color with the less difference is R76 G88 B38 of Euclidean distance=20, which thread code is DMC 936 (class name: Avocado Green-VY).

k-NN using RGB + Euclidean Distance

Quantized color

R:90 G:100 B:30
L:40.2161 A:-14.3470
B: 36.8525

The chosen (k=1)

R:76 G:88 B:38
No DMC:936
EucDistance: 20

The other that is not chosen (k=2 to k=10)

R90 G100 B34 No DMC:934 EucDistance:21	R90 G113 B51 No DMC:937 EucDistance:26	R90 G77 B53 No DMC:935 EucDistance:33	R94 G82 B48 No DMC:980 EucDistance:36	R99 G73 B55 No DMC:938 EucDistance:37
R99 G113 B25 No DMC:987 EucDistance:37	R94 G100 B50 No DMC:936 EucDistance:30	R93 G85 B45 No DMC:939 EucDistance:40	R98 G100 B40 No DMC:905 EucDistance:40	R95 G102 B72 No DMC:951 EucDistance:42

Fig 2 – Finding nearest color using RGB+Euclidean Distance

After a set of classification by RGB + Euclidean Distance, an RGB + Euclidean Distance codebook is obtained.

1. CIE LAB + CIE94: CIE94 will measure the distance between quantized LAB color values to a thread's LAB color value, the distance called as E_{94} (Delta E).

The formula of Delta E (ΔE) [7]:

$$E_{94} = \sqrt{\left(\frac{L}{k_L S_L}\right)^2 + \left(\frac{C_{ab}}{k_C S_C}\right)^2 + \left(\frac{H_{ab}}{k_H S_H}\right)^2} \quad (3)$$

TABLE 2 WEIGHTING FUNCTION K1, K1, K2 PARAMETER [7]

	Graphics Arts	Textiles
k_L	1	2
K_1	0.045	0.048
K_2	0.015	0.014

¹ The International Commission on Illumination (CIE) calls their distance metric ΔE^*_{ab} (also called ΔE^* , dE^* , dE , or "Delta E") where delta is a Greek letter often used to denote difference, and E stands for Empfindung; German for "sensation". The scale of Delta G is from 0 to 100:

For k_C and k_H value is always the same, and the default value is 1. While k_L , K_1 , K_2 depends on the color that is being compared, whether it's graphic arts or textile. The rule in the standard CIE94 for $k_L=1$, but for textile $k_L=2$ will result a better performance. [7]

E.g.: For R90 G100 B30, searching the nearest value color

thread using k-NN (k=1) and the metric used is CIE94. R90 G100 B30 then converted to LAB color L: 40.2161 A:-14.3470 B: 36.8525. The nearest color thread value found is L: 45.1454 A:-15.9742 B: 32.1664 with CIE94 Delta E=3.5176. The thread code is DMC 937 (class name: Avocado Green-MD)

k-NN using LAB+CIE94

Quantized color

R:90 G:100 B:30
L:40.2161 A:-14.3470
B: 36.8525

The chosen (k=1)

L: 45.1454 A: -15.9742
B: 32.1664
No DMC:937
DELTA E 1994: 3.5176

The other that is not chosen (k=2 to k=10)

L:562131 A: 13.4051 B:27.5183 No DMC:936 DELTA E 1994:4.0897	L:562934 A: 18.2545 B:24.3756 No DMC:969 DELTA E 1994:6.5294	L:308210 A: 12.3050 B:24.3756 No DMC:935 DELTA E 1994:6.6367	L:132800 A: 11.7907 B:18.9880 No DMC:932 DELTA E 1994:7.2426	L:462044 A: 26.6537 B:14.2653 No DMC:901 DELTA E 1994:7.2756
L:503333 A: 7.3462 B:40.8474 No DMC:730 DELTA E 1994:7.3463	L:446129 A: 18.4616 B:23.6995 No DMC:967 DELTA E 1994:7.5395	L:416504 A: 8.3777 B:16.1001 No DMC:951 DELTA E 1994:7.6699	L:548877 A: 8.1955 B:15.0112 No DMC:950 DELTA E 1994:8.0088	L:520789 A: 13.9478 B:24.5407 No DMC:9363 DELTA E 1994:8.5545

Fig 3 – Finding nearest color using LAB+CIE94

After a set of classification by LAB+CIE94, an LAB+CIE94 codebook is obtained.

C. Cross Stitch Patterns Validation

There are 3 images in the same size will be needed for validation: the original image, the cross stitch pattern made by, RGB+Euclidean the cross stitch pattern made by LAB+CIE94.

Color Coherence Vector (CCV) value is obtained from each image. To get the CCV value, the researcher use Matlab and the code getccv.m which made by Tarek Vito [8] and edit the numberofcolors=360, in order to make more detail color inspection. The number of color 360 is chosen because there are 360 color threads taken in the research.

Delta G is the distance between CCV of two images, the smaller Delta G means the less difference between the two images. The distance can be measured as the two images has the same size.

³ Consider two images I and I', together with their CCV's G_I and $G_{I'}$, and the let the number of coherent pixels in color bucket j be α_j (for I) and α'_j (for I'). Similarly, let the number of incoherent pixels be β_j and β'_j .

The Color Coherence Vector by Greg Pass [9] formula:

$$G_I = \langle (\alpha_1, \beta_1), \dots, (\alpha_n, \beta_n) \rangle \quad (4)$$

$$G_{I'} = \langle (\alpha'_1, \beta'_1), \dots, (\alpha'_n, \beta'_n) \rangle \quad (5)$$

$$G = \sum_{j=1}^n |(\alpha_j - \alpha'_j)| + |(\beta_j - \beta'_j)| \quad (6)$$

First, find the Delta G of the cross stitch pattern made by RGB+Euclidean to the original image. Second, find the Delta G of the cross stitch pattern made by LAB+CIE94 to the original image.

Which method is better can be done by comparing the first Delta G to the second Delta G. The smaller Delta G is the better method, because this means a less difference between the original and the pattern.

IV. EXPERIMENTAL RESULT

In order to test which codebook is better to make a cross stitch pattern, 32 images will be used. The variety of the image is full color, monochromatic, and grayscale. The quality of the image is also various from high quality from pixabay.com, test images from wisc.edu [10], and also underexposure images.

The most important validation is made quantitatively using CCV, but since this cross stitch pattern is about human art sense, qualitative result (through human perception) of which pattern is better also stated.

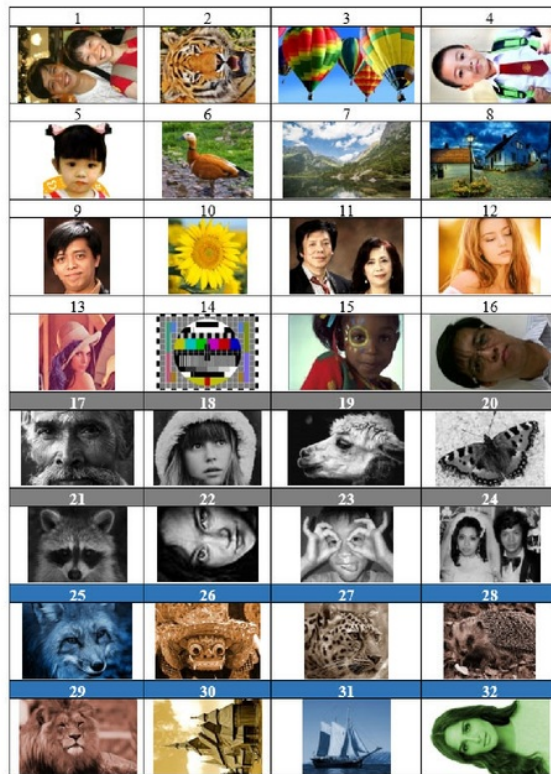


Fig 4 – The 32 Test images

Table 4 shows the qualitative validation result of the 40 patterns (32 patterns from LAB+CIE94 and 32 patterns from RGB+Euclidean) and also the quantitative result of human perception. The qualitative and quantitative result decides which pattern made is better. The table shows that from this 32 test images, 75% shows the same result of which pattern is

better.

TABLE 4 - VALIDATION OF CROSS STITCH PATTERNS THAT PRODUCED BY LAB+CIE94 AND RGB+EUCLIDEAN CODEBOOK

TABLE OF CROSS STITCH PATTERNS EVALUATIONS THAT ARE MADE BY CODEBOOK LAB+CIE94 DAN CODEBOOK RGB+EUCLIDEAN

img No	Color	Delta G (CCV)		Best Pattern Quantitative	Best Pattern Qualitative	Qualitative& Quantitative		
		LAB+CIE94	RGB+Eucl			RGB+Eucl	LAB+CIE94	Disagree
1	True color	3259	1863	RGB+Eucl	RGB+Eucl	•		
2	True color	1084	1000	RGB+Eucl	All	•		
3	True color	11100	10466	RGB+Eucl	RGB+Eucl	•		
4	True color	450	328	RGB+Eucl	RGB+Eucl	•		
5	True color	276	319	LAB+CIE94	RGB+Eucl			•
6	True color	1168	574	RGB+Eucl	All	•		
7	True color	2406	1888	RGB+Eucl	All	•		
8	True color	12228	8528	RGB+Eucl	LAB+CIE94			•
9	True color	3801	4344	LAB+CIE94	LAB+CIE94		•	
10	True color	662	620	RGB+Eucl	RGB+Eucl	•		
11	True color	2991	4735	RGB+Eucl	LAB+CIE94			•
12	True color	156	502	LAB+CIE94	RGB+Eucl			•
13	True color	1030	414	RGB+Eucl	RGB+Eucl	•		
14	True color	4682	5414	LAB+CIE94	LAB+CIE94		•	
15	True color	6557	6288	RGB+Eucl	RGB+Eucl	•		
16	True color	4222	4788	LAB+CIE94	RGB+Eucl			•
17	Grayscale	6357	8966	LAB+CIE94	LAB+CIE94		•	
18	Grayscale	4800	6485	LAB+CIE94	LAB+CIE94		•	
19	Grayscale	2290	2913	LAB+CIE94	LAB+CIE94		•	
20	Grayscale	1862	2262	LAB+CIE94	LAB+CIE94		•	
21	Grayscale	7151	9383	LAB+CIE94	LAB+CIE94		•	
22	Grayscale	691	1129	LAB+CIE94	LAB+CIE94		•	
23	Grayscale	2344	4061	LAB+CIE94	LAB+CIE94		•	
24	Grayscale	2097	3822	LAB+CIE94	RGB+Eucl			•
25	Monochrome	2112	4149	LAB+CIE94	LAB+CIE94		•	
26	Monochrome	2109	1304	RGB+Eucl	All	•		
27	Monochrome	2290	2392	LAB+CIE94	LAB+CIE94		•	
28	Monochrome	3596	2392	LAB+CIE94	LAB+CIE94		•	
29	Monochrome	8271	3693	RGB+Eucl	All	•		
30	Monochrome	1404	1556	LAB+CIE94	LAB+CIE94		•	
31	Monochrome	3510	5258	LAB+CIE94	RGB+Eucl			•
32	Monochrome	3888	5128	LAB+CIE94	RGB+Eucl			•

From the 32 cross stitch pattern set, there are interesting similar cases that shown in this 7 cross stitch pattern sets (sample pattern shows across A-G):

A. Image: David-vointa-nicelight.jpg

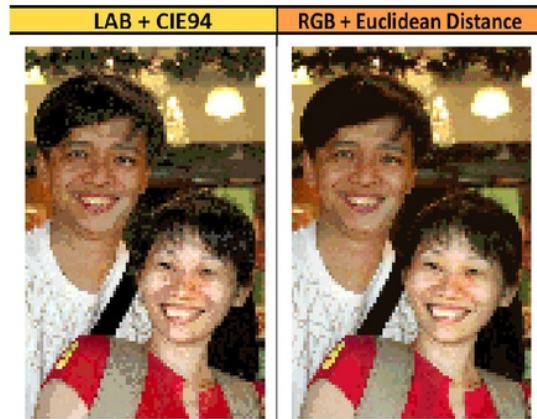


Fig 5a – Cross stitch pattern previews made from Image Test Subject 1

The validation of two patterns using Color Coherence Vector (CCV) result:

- Delta-G for LAB+CIE94 cross stitch pattern = 3259.

- Delta-G for RGB+Euclidean cross stitch pattern = 1863.
- Best: RGB+Euclidean = $((3259/1863)*100)-100 = 75\%$

Qualitative Assessments:

- LAB+CIE94 pattern has a lot of green colored noise on the hair and more contrast color gradation on the skin, that makes the skin is coarse / rugged.
- RGB+Euclidean pattern has softer skin's color gradation.

The green colored noise in the hair image does not exist in the original picture. The researcher examines one of the coordinates that has the "green hair" problem in both patterns.

The color in specific coordinates that has the "green hair" problem of the original image is R25 G26 B12, which followed the quantization color of R30 G30 B10 or L:10.7513 A:-3.7915 B:11.8382 The nearest thread's color value :

In LAB+CIE94 codebook is L= 22.4768 A=-9.5154 B=18.7057 (a dark green). DMC 934.

In RGB+Euclidean codebook R30 G17 B8 which color belongs to DMC 3371 (dark brown).

The different choice of the two codebooks can be observed in Figure 5b.

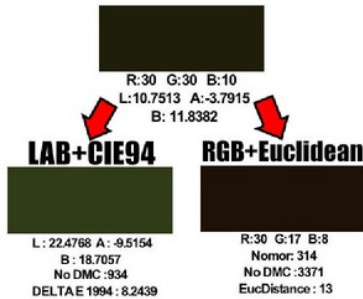


Fig 5b – The different classification for R 30 G 30 B 10

B. Image: *lena.png* [10]

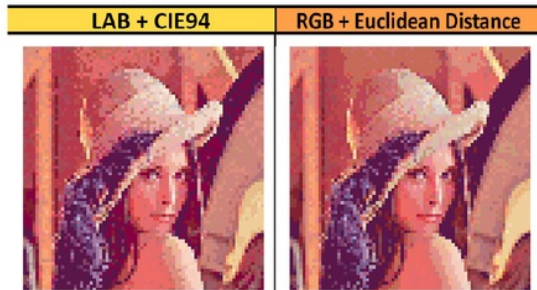


Fig 6 – Cross stitch pattern previews made from Image Test Subject 13

The validation of two patterns using Color Coherence Vector (CCV) result:

- Delta-G for LAB+CIE94 cross stitch pattern =1058.
- Delta-G for RGB+Euclidean cross stitch pattern = 432.

- Best: RGB+Euclidean = $((1058/432)*100)-100 = 145\%$

Qualitative Assessments:

- Both patterns are good representing the original image.
- RGB+Euclidean pattern has softer gradation which can be observed in the shoulder and the hat and wall.
- Best: RGB+Euclidean (equal to CCV).

C. Image: *girl-cae.wisc.edu-Fabien a. p. petitcola.png* [10]

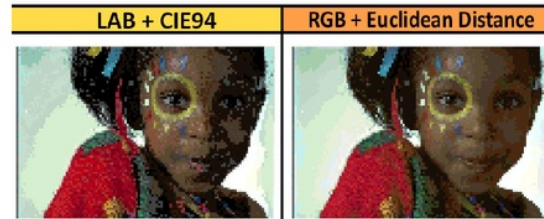


Fig 8 – Cross stitch pattern previews made from Image Test Subject 15

The validation of two patterns using Color Coherence Vector (CCV) result:

- Delta-G for LAB+CIE94 cross stitch pattern = 6557.
- Delta-G for RGB+Euclidean cross stitch pattern = 6288.
- Best: RGB+Euclidean = $((6557/6288)*100)-100 = 4\%$

Qualitative Assessments:

- The girl's skin on the LAB+CIE94 pattern shows a more contrast color, that looks the coarse/ rugged skin
- Best: RGB+Euclidean (equal to CCV).

D. Image: *lowquality.png*

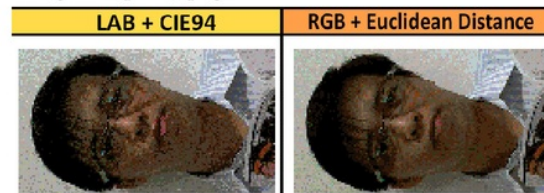


Fig 9 – Cross stitch pattern previews made from Image Test Subject 16

The validation of two patterns using Color Coherence Vector (CCV) result:

- Delta-G for LAB+CIE94 cross stitch pattern = 2066.
- Delta-G for RGB+Euclidean cross stitch pattern = 2390.
- Best: LAB+CIE94 = $((104/102)*100)-100 = 16\%$

Qualitative Assessments:

- Both patterns are not so good because of the input image is an underexposure photo. The rgb+euclidean pattern shows a softer gradation and less noise.

- Best: RGB+Euclidean (different choice than CCV).

E. Image: *indiadelhi-wikimedia-jorgeroyan-grayscale.jpg*

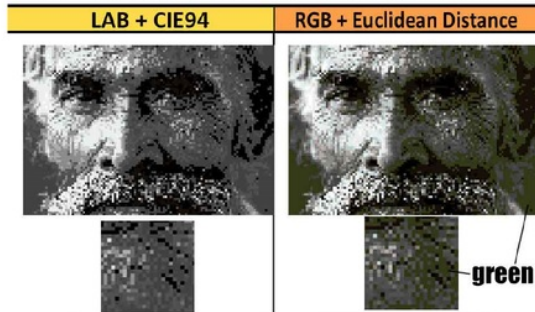


Fig 7a – Cross stitch pattern previews made from Image Test Subject 17

The validation of two patterns using Color Coherence Vector (CCV) result:

- Delta-G for LAB+CIE94 cross stitch pattern = 6357.
- Delta-G for RGB+Euclidean cross stitch pattern = 8966.
- Best: LAB+CIE94 = $((8966/6357)*100)-100 = 41 \%$

Qualitative Assessments:

- LAB+CIE94 pattern has all the grayscale color similar to the original image, while RGB+Euclidean pattern has the grayscale color and green color
- Best: LAB+CIE94 (equal to CCV).

Figure 7b shows that R50 G50 B50 in the original image's cheek are classified to a different color while using a different codebook.

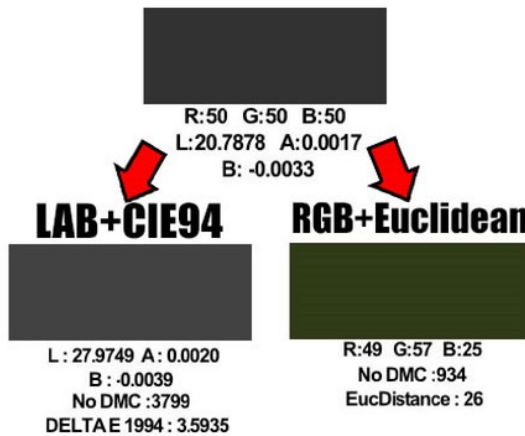


Fig 7b – The different classification for R 50 G 50 B 50

F. Image: *Fashion-1623083-pixabaycom-elanusa.jpg*

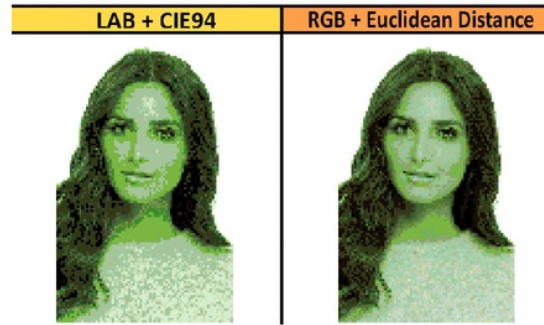


Fig 8 – Cross stitch pattern previews made from Image Test Subject 32

The validation of two patterns using Color Coherence Vector (CCV) result:

- Delta-G for LAB+CIE94 cross stitch pattern = 3888.
- Delta-G for RGB+Euclidean cross stitch pattern = 5128.
- Best: LAB+CIE94 = $((5128/3888)*100)-100 = 32 \%$

Qualitative Assessments:

- Both pattern made good results, but the RGB+Euclidean made softer gradations in the face and in the neck.
- Best: LAB+CIE94 (different from CCV).

G. Image: *PM5544_with_non-PAL_signals.jpg* [10]

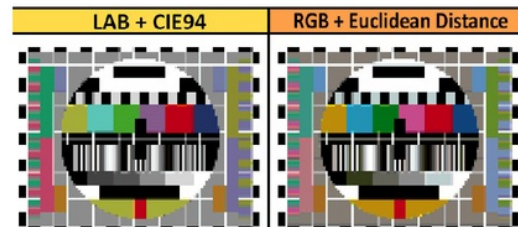


Fig 9 – Cross stitch pattern from PM5544_with_non-PAL_signals.jpg

The validation of two patterns using Color Coherence Vector (CCV) result:

- Delta-G for LAB+CIE94 cross stitch pattern = 4682.
- Delta-G for RGB+Euclidean cross stitch pattern = 5414.
- Best: LAB+CIE94 = $((5414/4682)*100)-100 = 16 \%$

Qualitative Assessments:

- Both patterns color results have their own preferences, and similar to the original image. But LAB+CIE94 pattern has the gradation of grayscale color perfectly, while the RGB+Euclidean interpret the grayscale colors in the original image into dark green and light blue.

- Best: LAB+CIE94 (equal to CCV).

H. Cross Stitch Pattern to Real Stitch

The researcher made a software named Divine Pattern, which using the algorithm in this paper, and made cross stitch patterns. The patterns are tested and made to be a real stitching artwork.

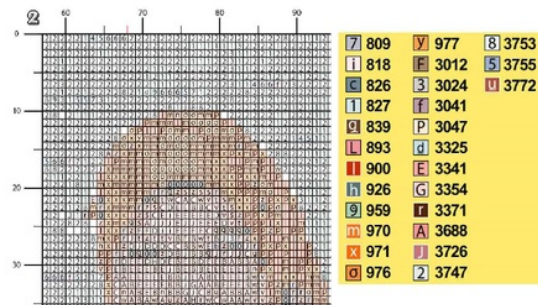


Fig 10 – Cross Stitch Pattern and Symbol Decoder to thread number



Fig 11 – Dewi Saidt (Pattern made with Divine Pattern)



Fig 12 – Beatrix Wu (Pattern made with Divine Pattern)



Fig 13 – Irma Hadiwijaya made a cross stitch for her pet

V. CONCLUSIONS

The conclusions of CCV's validation for the 32 sets of cross stitch patterns made by using RGB+Euclidean distance codebook and LAB+CIE94 codebook are:

1. The LAB+CIE94 codebook is 100% suitable for making grayscale cross stitch patterns. (CCV)
2. The LAB+CIE94 codebook is 75 % suitable for making monochromatic cross stitch patterns. (CCV)
3. The RGB+Euclidean codebook is 68% suitable for full-color images. (CCV)
4. RGB+Euclidean codebook conducts a better color gradation and softer skin look. (Qualitative)
5. Quantitative selection using CCV and Qualitative Selection shows the same choice as 75%. (24 of 32 select the same cross stitch pattern as the best pattern).
6. One single color point or pixel in a cross stitch pattern has a contribution to whole picture meaning. A white point in a black hair can be considered as dandruff, in the future development, it is hoped that each point or pixel meaning to be defined with Computational Intelligence. The point or pixel there in the image is part of human skin, a leaf, or stone, so it's will be more appropriate to pick which nearest color.

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